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THE TERMINAL MORaine OF THE PUGET SOUND GLACIER

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I. GENERAL CHARACTER OF THE COUNTRY SOUTH OF PUGET SOUND

The region of Puget Sound, inclosed between the Olympic and Cascade ranges, is a heavily drift-covered lowland. The drift is deeply incised by broad valleys of meridional trend, some occupied by arms of the Sound, some by lakes, and others by streams. The summits of the plateaus and hills of drift accord in a general level so that, seen from overlooking mountain peaks, the region appears to be a vast plain, interrupted only by a few rock hills, remnants of the preglacial topography rising above the drift.

Immediately south of the Sound the drift assumes a different facies. The trough valleys disappear and the plain becomes continuous and is widely covered with gravel outwash. It is still a part of the great Puget Sound drift plain. It is diversified with morainic eminences occasionally, of a character different from that of the drift hills lying between the valleys of Puget Sound farther north. The most southerly extended of these hills is a belt which constitutes a part of the terminal moraine of the Puget Sound glacier.

Beyond the southern portion of the Puget Sound depression is an abrupt transition in the topography. Rock hills of preglacial sculpture, lying beyond the limit of glaciation, begin here and continue southward past the Columbia. In western Washington no other such area of low rock surface occurs as must here exist beneath the heavy drift mantle of Puget Sound.

On the southeast, the area is overlooked by the magnificent Tertiary volcano Rainier. On the south is a region of rock hills bearing no group name. They are drained by the upper Des Chutes and the Skookum Chuck rivers and have a maximum altitude of about 2,000 feet. Farther west lie the Black Hills, whose highest altitude is probably not greater than 2,000 feet.

These hills are bounded on the east and northwest sides by low, wide valleys which constituted the two chief routes of glacial water discharge from the basin of Puget Sound. The Olympic foothills rise farther northwest in the main Olympic Range. At the time of greatest extent of the ice, the northern slope of the Black Hills was overridden and a lobe extended down on either side, the hills determining a broad re-entrant in the ice front.

II. PREVIOUS WORK ON THE MORaine

In a general way, the glacial drift in Puget Sound has long been known to terminate some distance south of Olympia, and the gravel plains have been commonly recognized as outwash deposits from the ice. No detailed work, however, has been done in the region except by Willis and Smith on the Tacoma quadrangle.¹ Here the contact between Pleistocene deposits from the glaciers of the Cascades and Mt. Rainier and the Puget Sound drift has been traced along the northwest flank of the volcano to the southern edge of the quadrangle.

Warren Upham has described,² from a hasty reconnaissance, what he believed to be the terminal moraine lying between the base of Mt. Rainier and the Black Hills. He interpreted the remarkable gravel mounds of the outwash plains of the region as morainic topography of peculiar type.

No observer, so far as the writer is aware, has previously noted the existence of the western lobe of the glacier, lying between the Olympic Mountains and the Black Hills.

III. MORaine COURSE ACROSS THE GEOSYNCLINE

The westernmost geosyncline of North America is regarded by stratigraphers as finding its representative on the Washington coast in the Puget Sound depression. Were it not for the accident of glaciation, this structural valley would today embrace a broad inland sea, but the thick drift deposit constitutes a filling sufficient to maintain most of the surface above sea-level. The terminal

¹ Bailey Willis and G. O. Smith, "Tacoma Folio, No. 54," *U.S. Geol. Survey*.

² Warren Upham, "Glacial and Modified Drift in Seattle, Tacoma and Olympia," *American Geologist*, XXIV, No. 4.

and its incompleteness must largely be charged to the same reason. Large tracts about Puget Sound are yet covered with virgin forest whose density is such that passage for any considerable distance is next to impossible. The lack of roads, trails, and inhabitants over many square miles forces the investigator to shoulder his pack of blankets and food, and travel the country on foot. Detailed work is not practicable under these circumstances. It will probably be years before the moraine can be mapped with accuracy, since the task must wait on the agricultural development of the country.

On the eastern margin of the Tacoma quadrangle, Willis and Smith¹ found a broad sheet of till spread by a piedmont glacier from the Cascades. The contact between this drift sheet, named the Osceola till, and the Vashon or youngest till sheet of the Puget Sound glacier was found to be marked by a belt of hummocky topography of morainic aspect, considerably different from that of the ground moraine on either side. No definite marginal or interlobate moraines were found, the phenomena being apparently referable to subglacial accumulation. Short eskers were a notable feature.

This study has taken up the continuation of the contact between local glacial deposits, and those far traveled down the Puget Sound depression from the north, on the south edge of the Tacoma quadrangle in a densely wooded country traversed by a few secondary roads and one highway, the Mt. Rainier automobile road. The geological map of the Tacoma folio maps the Rainier Pleistocene drift on the south edge of the quadrangle, farther west than the writer has found it. The automobile road follows a north to south course for 5 or 6 miles, parallel to and about 6 miles west of Lake Kapowsin, and for this whole distance traverses the till plain of the Puget Sound Vashon glacier. Northward toward Tacoma are extensive areas of outwash gravel deposited during the recession of the Puget Sound ice. The till plain rises southward from the outwash with an abrupt morainic slope, ascending 200 feet in one mile. The slope is thrown into several successive ridges of till trending east to west, on the south sides of some of which were

¹ Bailey Willis and G. O. Smith, *op. cit.*

distinct kames. The till is the characteristic blue-gray arenaceous material, with laminae and rounded cobbles, which is identified throughout the Puget Sound country as Vashon. The presence of numerous varieties of rolled granite cobbles in the moraine and in the plain southward is a safe criterion for the identification of the till as the Vashon rather than the Osceola till of the Cascades. The moraine ridges on its northern flank and broad till plain lying southward are topographic features in accord with this interpretation. Though the boundary between Vashon and Osceola till was not located, it obviously lies between the Mt. Rainier highway and Lake Kapowsin, the lake lying at the base of the foothills of Mt. Rainier.

The dominance of Puget Sound ice at the western base of the Rainier foothill country is proved conclusively by the common occurrence of boulders and cobbles of several granitic types characteristic of the drift of Puget Sound and unknown to the adjacent Cascades.

The postglacial gorge of Nisqually River, 300 feet in maximum depth and with vertical and even overhanging walls, is two miles long and occurs where the river enters the area of Puget Sound drift. A 40-foot section of outwash, containing frequent Vashon drift materials, overlies the rock floor in which the canyon is cut at LeGrande. Farther up the canyon no drift was found.

A trail crosses the divide between the Nisqually and Des Chutes rivers just south of the canyon noted, entering the latter stream at the headwaters. Scattered granitic boulders of Vashon drift were found up to an altitude of 1,220 feet on the Nisqually side, but no traces of drift were found in the remaining 200 feet of ascent or in the valley of the Des Chutes on the other side until the altitude of 1,200 feet was reached, a few miles down from the headwaters. Here scattered erratics occur on the hillsides, and at 900 feet is a level terrace composed of fine material with interspersed pebbles, probably a lacustrine deposit caused by the ice entering the lower valley and blocking the drainage.

Two miles below this terrace, whose soil has determined the location of several small farms in the wilderness, is found the terminal moraine of the Puget Sound Vashon glacier. The surface is exceed-

ingly bowldery, granite is very abundant, kettles containing lakelets and bogs are common, and the subsoil is typical Vashon till. The margin of this bowldery drift may be traced about the west and north of the Bald Hills from the Des Chutes to the Nisqually River and is in places thrown into sharply defined ridges. Occasionally the forest seems growing on one gigantic boulder heap. A preglacial valley descending to the northwest has been dammed, giving rise to Little Bald Hill Lake, a picturesque body of water in the heart of the wilderness. Another such valley has three morainic ridges thrown across it at descending altitudes, a marsh or alluvial flat lying behind each ridge. Pronounced relief of the moraine on the north slope of the Bald Hills was found, but the unbroken forest prevented satisfactory examination.

The same difficulty of examination is presented by most of the country from the Bald Hills west to Tenino. In general, the drift-covered area bears the farms and roads, the region immediately beyond the ice limit rising in rocky hills which constitute the divide between the Des Chutes River and the Skookum Chuck. A traverse across this divide found the moraine disposed in bowldery ridges along the base of the hills with a marginal drainage channel separating the frontal ridge from the bold rock hill slope. No erratic material or evidence of ice action was found on the ascent to the divide crest, the glacier of Puget Sound having succeeded in barely reaching the northern base of the hill region.

The town of Tenino is situated on an area of gravel outwash lying immediately south of the moraine. The rock hills die away toward the west just south of the town and glacial drainage escaped southward to the lower Skookum Chuck through a broad, gravel-filled valley. Glacial outwash was also carried westward from Tenino toward Grand Mound and Gate to join the extensive areas there outspread.

The Skookum Chuck bears a train of glacial gravel which entered it somewhere in the unsurveyed region of the Huckleberry Mountains, presumably from Mt. Rainier's Pleistocene glaciers. But careful search revealed absolutely no granite or sedimentary metamorphics in this gravel for a distance of 6 miles along its course. Only when the western limits of the rock hills were approached,

and below a low pass across the divide to the Des Chutes River, was Puget Sound glacial gravel found in the Skookum Chuck valley.

Clear Lake, at McIntosh station, 4 miles east of Tenino, lies in a marginal drainage channel discharging westward into the outwash gravel area at Tenino. The terminal moraine lies immediately north of this lake. North of Tenino, the moraine is of a character considerably changed from that in the Bald Hill region. It has here become a single massive till ridge on the plain, and surface boulders are not sufficiently numerous to attract attention. It is two miles wide and 250 feet above its base on both north and south sides, the highest point examined reaching 550 feet A.T. On each side, it is flanked by an outwash gravel plain bearing peculiar tumuli. The till mass appears to cover several rock knobs and hills, whose existence may have in some measure determined its location and relief. Both east and west of Tenino, quarries in sandstone have been opened on the slopes which rise farther to the north in the moraine. The road north from Tenino to Olympia cuts into decayed shale strata *in situ* at the summit of its grade across the moraine at about one-half the maximum height of the moraine, and at McIntosh rock outcrops occur on the south base of the moraine.

The hills which rise south of Tenino were carefully examined for drift materials. Three distinct terraces of outwash gravel were found, occasionally showing forest beds descending southward toward the Skookum Chuck. The highest gravel lies 360 feet A.T., and above it drift abruptly ceases.

Flanking the frontal margin of the moraine from Tenino west to Black River is an extensive area of outwash gravel, known as the Grand Mound Prairie. It is entirely barren of forest growth and almost useless for any agricultural purpose because of the coarseness and depth of the gravel. At the contact between moraine and outwash examined no apron structure was found. The gravel plain apparently was built by outwash occurring through breaks in the moraine ridge and not by outflow from the ice edge when standing at its maximum limit.

The whole region south of Puget Sound bears much outwash, both

extra-morainic in position and lying back of the ice limit. These areas are all alike in being natural prairies because of the coarseness of the soil and in bearing a surface deposit of black silt of variable thickness. Many of them exhibit a very interesting surficial development into mounds of fairly uniform size and distribution composed of mingled gravel and silt without stratification. Where typically developed, they resemble a field of closely spaced haystacks. Their origin is not clear. Grand Mound Prairie bears these tumuli over a considerable portion of its extent.

Some distance back from the frontal edge of the terminal moraine between Tenino and Little Rock a new railroad grade affords frequent exposures of the Vashon till overlying drift of much greater age and with bedrock often appearing beneath the drift. Hills of the moraine occur on the east side of Black River a mile south of Little Rock, while across the river on the west, a morainic tract of low relief occurs about a mile wide. In this tract is a splendid exposure of Vashon till highly charged with rounded gravel which is doubtless overridden and incorporated outwash material.

Mima Prairie, southwest of Little Rock, is another part of the outwash gravel plain and forms a sharp re-entrant angle in the surface till exposures, though hardly recording such an ice margin form, the till being probably buried beneath this northward angle of the outwash. Between Mima Prairie and the Black Hills, unweathered Vashon till was observed in a gravel pit with a thickness of three feet overlying a very red and decayed till of undetermined depth. Small pebbles of the latter were often easily cut in two with a knife, while those of the overlying Vashon were firm and unweathered.

No drift is found back in the Black Hills except a sprinkling of pebbles in re-arranged residual material on the slopes which face the broad drift plain eastward. The region is exceedingly difficult to examine, the forest being almost impassable. Entrance into the hill region is gained on a logging railroad and on various trails. One road crosses near the northern part of the hills, passing west from Olympia close to Summit Lake. Drift has been found near this lake on the north slope of the hills up to an altitude of 1,460

feet, falling short a few tens of feet of reaching the summit. No till has been found in the valleys of any of the south-flowing streams of the region.

Summit Lake lies in the upper part of a preglacial valley, the lower southern portion of which bears a drift filling. The ice sheet certainly overrode the divide at the northeast of Summit Lake but it brought over no drift. Farther south, however, the valley opens into a larger one trending east and west, and from both directions in this, till was carried into the Black Hills. Again the relation of agriculture to the drift is illustrated in the occurrence of several small farms on the broadened valley floor produced by drift filling while elsewhere the region is covered with primeval forest or the waste of logged-off land.

At least two distinct valley trains cross the western part of the Black Hills to the Chehalis River, the larger of these being a filling so complete that several rock hills rise like nunataks from the gravel plain. This enters the Chehalis valley at Elma, in the vicinity of which it is deeply incised by creeks, its structure being thus plainly revealed. A feature of the gravel is the prevailing reddish color, fairly uniform throughout the mass. The freshness of the pebbles and the youthfulness of drainage on the plain, however, show this staining to be due to some other cause than age. The Vashon till near the head of this valley train is also deeply red while its pebbles are fresh. The explanation is thought to be found in the incorporation of residual material from the basalt rocks of the Black Hills.

The country lying between these hills and the Olympic Mountains is practically a great gravelly waste. The forest is thin over large areas and open prairies occur in the region south of Hood's Canal. The moraine hills when found are often largely buried in outwash and the extreme limit of the ice as mapped is consequently only approximate, being based on the occurrence of till outcrops above the gravel plain. No definite ridging tangential to the ice margin was observed in the till hills seen, though their occurrence forms a zone a few miles wide, whose outer margin has been indicated as the limit of Puget Sound ice to the west.

The character of the till, where exposed in railroad cuts and

stream valleys, appears identical with that shown in the vicinity of Seattle, on the slope of the Bald Hills, and in other widely separated regions. The matrix is somewhat sandy, the pebbles and boulders are rounded, and large erratics are rare. Granite of various kinds is abundant, though granite is not known in the neighboring Olympics. The till is seen to overlies fresh gravel in a few sections with a thickness of about three feet. Its altitude probably does not reach much above 450 feet A.T.

Lake Nahwatzel lies in a decidedly morainic area, the monotonous gravel plain giving place to rolling hills of till which rise 50 feet above the lake surface. These morainic hills lie probably over the lowest preglacial rock surface between the Black Hills uplift and the Olympic foothills, and in such a situation we may find an explanation of the more pronounced morainic expression.

The till along the margin from Matlock to the Black Hills often shows a large proportion of deep red clayey material intermingled with fresh pebbles. The presence of such material, doubtless from the incorporation of the residual soil of basalt of which there are frequent outcrops, is to be expected near the ice margin providing the ice was overriding a region previously unglaciated.

The approximate moraine course from Matlock northward bends abruptly back toward Hood's Canal, the greater length of which is closely bordered by the Olympic Mountains on the west. The extent to which Puget Sound drift penetrated into the valleys of these mountains is known in but one case, that of the Skokomish River. Rock along this stream's course is practically absent below Lake Cushman, while the mountain walls rise almost from the lake shores on the upstream side.

Puget Sound drift of Vashon age composes an extensive plateau 400-800 feet above Hood's Canal, extending back from Lilliwaup Creek directly west to Lake Cushman and also southward to the broad, pre-Vashon lower Skokomish valley. One large rock hill rises through this till plateau just south of the Lilliwaup, otherwise the surface is of rolling ground moraine with occasional shallow kettles. Across the Skokomish to the west are foothills with little or no drift. To the south of the great bend of this stream, extensive

outwash gravels begin, continuing to Shelton in one direction and across the Puget Sound divide to the Satsop in another. In this latter direction, the outwash largely buries the moraine near Matlock and becomes extra-morainic in its further extent.

On the east side of Lake Cushman, the till plateau becomes ridged and kettley, though a dense forest prevents satisfactory examination. The morainic character is best seen along the trail from the head of the lake to Lilliwaup. The material on the lake-ward face of these ridged drift hills nowhere contains granite, though two very careful examinations were made. In but one place are granite pebbles found on the shore or in the immediate vicinity of the lake, this being in the bed and delta of the largest stream entering the lake from the northeast. Yet a mile back from the lake, to the east, granite boulders are found lying on the surface, becoming very numerous two or three miles farther east.

The limit of the Puget Sound drift is thus seen to lie close to the lower end of Lake Cushman, the basin of which is caused by the damming of the Skokomish River valley. The inner slope of the drift dam is probably faced with the terminal deposits of the Skokomish valley glacier, which was unable to advance farther in the face of the overwhelming mass of the Vashon glacier. It may have earlier deployed farther out on the plain, but if so the deposits are buried beneath the Vashon drift. That a valley glacier must have existed back of the drift dam of Lake Cushman when the Puget Sound ice was at its maximum is evident, else the lake basin would have filled with outwash. A till with very angular *débris*, none characteristic of Puget Sound drift, lies back of the drift dam on the slope of Mt. Ellinor, immediately north of the lake. It is estimated to reach 500 feet higher than the lake surface.

As shown on the map, the western margin of the Puget Sound glacier north of Lake Cushman is approximate only. The mountains rise close to Hood's Canal throughout the remaining distance included in the accompanying map, and in all probability there existed no embayment of Puget Sound ice in the other river valleys entering the Canal comparable to that of the Skokomish valley.

IV. GENERAL CONSIDERATIONS

Considering the altitudes of the terminal moraine only where facing driftless country to the south, its crest is found to have no great range in elevation above the sea. On the north slope of the Bald Hills, near the headwaters of the Des Chutes River, the moraine crest is probably nowhere more than 900 feet A.T., though erratics occur 320 feet higher. Near Tenino, where the moraine is most typically developed on the plain, the crest is probably less than 600 feet in altitude. The existence of buried rock hills in the moraine in this region has been noted. At Little Rock, the moraine surface on the west side of Black River can hardly have been lowered by erosion of escaping glacial water or subsequent stream action, and is approximately 150 feet above the sea, the lowest altitude in the moraine. From this altitude is a descending slope southward, on which the ice ceased to advance. The opposing northern flanks of the Black Hills, deeply cut by valleys, did not permit assumption of the moraine form. Drift, however, has its upper limit in the re-entrant angle which they produced, at an altitude of 1,460 feet. The flattened lobe northwest of these hills has its moraine hills about Lake Nahwatzel at 450 feet A.T. Puget Sound and Olympic drift damming Lake Cushman reaches observed heights of 950 feet above the sea.

The data available for an estimate of the thickness of the ice and its frontal slope are meager. Three miles from Little Rock, the glacier left its till at the eastern foot of the Black Hills at an altitude of about 150 feet. From here it is 10 miles north to the upper drift limit near Summit Lake, at 1,460 feet A.T. The slope in this instance is approximately 130 feet per mile. Fifteen miles east of Seattle rises the peak of Mt. Issaquah, about 3,000 feet A.T., whose frost-riven summit bears no residual soil comparable to that found on hills of much the same lava rock beyond the limit of the drift. Scattered erratic pebbles were found on the summit, their number increasing on the lower slopes. With the maximum depth of the Sound near Seattle at 964 feet, we may conclude that in the latitude of Seattle the glacier attained a thickness of 4,000 feet, allowing very little for central surface convexity, which would increase the estimate an unknown amount.

Evidence of the lack of vigorous movement near the frontal margin of the glacier is shown in the occurrence of deeply decayed material overridden by the ice. Shale strata, profoundly decomposed, are exposed east of Little Rock. Though slightly crumpled and in one case bearing an intruded arm of the till, this incoherent and rotted shale has been but little eroded by the ice, though it is two or three miles back from the moraine front. West of Little Rock, where Vashon till is found at its farthest southern extent along the Black Hills, a knob of old red till is exposed beneath it. Depth of weathering and staining are the same on the slopes as on the summit of this knob, hence the inference that no erosion of the projecting softened till was produced by Vashon ice.

The accompanying map indicates only the extra-morainic outwash. Great areas lie within the moraine limits of essentially the same character and age. In the case of all outwash deposits, the discharging water was received by the Chehalis valley largely on the east or west side of the Black Hills. Extensive tracts are rendered as worthless for agriculture by these outwash plains as though in an arid country. For example, the road through the sparse forest extending from Lake Nahwatzel to Shelton crosses but one stream bed and this carries water only during the very rainy winters and no valley has been cut. As already noted, the moraine across the low area between the Black Hills and the Olympic foothills has been partially buried in the flood of gravel and its relief much reduced.

The question of contribution from valley glaciers in the bordering Cascades and Olympics cannot be adequately treated in our present state of knowledge. Valley glaciers in these mountains on the Soundward slopes debouched into a great mass practically filling the depression from rim to rim. That they would perform much erosion under such conditions is not to be expected. Willis has found the till sheet of a Cascade piedmont glacier on the eastern part of the Tacoma quadrangle, a part of which is indicated on the accompanying map. The relative insignificance of the Skokomish glacier whose lower extremity occupied the basin of Lake Cushman has been shown. No evidence has yet been found that tributary glaciers north of these two produced any perceptible

effect on the mass of the course of the great Vashon glacier, whose volume and thickness was of course greater northward.

Definite recessional moraines are yet unknown in the Puget Sound country. Between the terminal moraine and the southern arms of the Sound are occasional moraine hills and ridges which will probably resolve themselves into linear arrangement when carefully studied and will constitute recessional moraine deposits. But in the larger area of longitudinally ridged drift among the arms of the Sound, there is little of morainic origin beyond scattered lodge moraine hillocks in the valleys.

Russell¹ first noted that there are two till sheets in Puget Sound basin, recording two glaciations. Willis² has named these the Admiralty and Vashon, with the latter of which we have had to do. The frequently weathered condition of the Admiralty till or of its superposed outwash has been pointed out by Willis as evidence of long exposure before the Vashon glaciation. The freshness and slight erosion of the Vashon till sheet and moraine evince an age comparable to that of the Wisconsin drift.

A notable feature of the Puget Sound glaciation, shown by the failure of constant careful search to find older till beyond the moraine, is that the last glaciation of the region, doubtless Wisconsin in age, was the most extensive. Frequent incorporation of residual soil in the Vashon till is the best evidence which might be secured, in the absence of deep sections, that it overlies areas never previously glaciated.

¹ Bailey Willis, "Drift Phenomena of Puget Sound," *Bull. Geol. Soc. Am.*, IX.

² Willis and Smith, "Tacoma Folio No. 54," *U.S. Geol. Survey*.